academicJournals

Vol. 12(19), pp. 2633-2639, 8 May, 2013
DOI: 10.5897/AJB12.2931
ISSN 1684-5315 ©2013 Academic Journals
http://www.academicjournals.org/AJB

African Journal of Biotechnology

Full Length Research Paper

Diesel engine performance and emission analysis using soybean biodiesel

Maurício Guy de Andrade*, Jair Antonio da Cruz Siqueira, Helton Aparecido Rosa, Luiz Inácio Chaves, Carlos Eduardo Camargo Nogueira, Samuel Nelson Melegari de Souza, Deonir Secco and Reginaldo Ferreira Santos

UNIOESTE, Western Paraná State University, Post-graduation Program, Master Course of Energy in Agriculture, Rua Universitária, 2069, CEP: 85.819-130 Bairro Faculdade, Cascavel, Paraná, Brasil.

Accepted 5 April, 2013

Biodiesel presents a large potential for replacing other fossil-based fuels. Thus, the present work aimed to assess the specific fuel consumption (SFC), thermal efficiency and emissions of nitric oxide (NO) and nitrogen oxides (NOx), in a cycle diesel engine-generator set, using soybean biodiesel and diesel as fuels. The experiment was carried out at Western Paraná State University (UNIOESTE), Cascavel Campus. The engine-generator set used in the study was a model BD 6500CF with 7.36 kW (10 cv) of power and 5.5 kVA/5.0 kW of nominal power, with an average output tension of 120/240 V monophase. Fuels used were soybean biodiesel (B100) and diesel oil (B0). Nominal loads applied varied between 1.0 and 5.0 kW. In order to quantify gas emissions, a combustion and emission quality analyzer was used; model PCA®3, Bacharach inc. Soybean biodiesel presented an average consumption increase of 4.3% in all resistive loads, what shows large potential for the usage of soybean biodiesel in the generation of energy, without causing raises in the specific fuel consumption. Soybean biodiesel efficiency has proved to be superior to that of diesel in all resistive loads. As for the emissions, soybean biodiesel provided a reduction of 64% (NO) and 54% (NOx) when compared with diesel oil.

Key words: Combustion gases, energy generation, specific fuel consumption.

INTRODUCTION

Forecasts related to the depletion of fossil-based fuels make necessary the search for alternatives that may replace them in an effective way. The main features required for these sources are that they must be renewable and cause less impact in the environment. Among them is biodiesel, which is a renewable fuel made of vegetal oils, such as sunflower, soybean, babassu or other plants with oilseeds, animal fat, or even the usage of residual frying oil. It is used in cycle diesel engines, in any rate with mineral diesel, or pure. It is produced by means of chemical processes, such as transesterification, which is the most used one.

According to Gerper (2005), transesterification is a chemical reaction of a vegetal oil or animal fat with an alcohol, such as methanol, in the presence of a catalyst, which is usually a strong base, such as sodium or potassium hydroxide, and produces new chemical compounds called methyl esters, which have been known as biodiesel.

Biodiesel is used as a replacement for diesel in cycle diesel engines, with the advantage of not requiring mechanical adaptations and presenting high energetic yield (Volpato et al., 2012).

*Corresponding author. E-mail: mauricio.agro@hotmail.com. Tel: (55) 45 -99247221.

The main advantages of using biodiesel in relation to diesel are the following: sulfur emissions are essentially eliminated, its high number of cetane, its high flash point (what provides better safety in handling and storage) and its lubricity. However, the problem is its viscosity, but it can be overcome by mixing it with a biodiesel with lower viscosity, what keeps elevated lubricity and oxidative stability (Flores et al., 2012).

In Brazil, soybean oil is the main feedstock for biodiesel production; it is currently responsible for about 78% of the total production (ANP, 2012). Soybean biodiesel is highly explored due to the fact that its feedstock is abundant and to better knowledge of obtainment processes (Kohlhepp, 2010).

According to Costa Neto (2000), in order to assess the fuel quality of vegetal oils, it is necessary to analytically determine their calorific power, cetane index, distillation curve and viscosity. To be used as a fuel, biodiesel must present some technical features such as complete trans-esterification reaction (total absence of fatty acids) and high purity without traces of glycerin, residual catalyst or alcohol that exceeded the reaction.

Volpato et al. (2009) tested the performance of a cycle diesel engine, by using soybean biodiesel (B100), in relation to diesel, and assessed efficiency, reduced power, specific fuel consumption and energy. Pereira et al. (2007) analyzed mixtures of B20, B50, B75 and B100 of soybean biodiesel with diesel in a stationary diesel engine; the results show an increase in fuel consumption, decrease in the temperature of exhaust gases and reduction of exhaust gases concentrations.

The objective of the present study was to assess specific fuel consumption, efficiency and emissions of nitric oxide (NO) and nitrogen oxides (NOx) of a diesel cycle engine-generator set running on soybean biodiesel (B100) in relation to diesel.

MATERIALS AND METHODS

The work was carried out at the Bioenergy Laboratory of Western Paraná State University (UNIOESTE), Cascavel Campus. A cycle diesel engine-generator set was used with direct injection; model BD 6500CF with 7.36 kW (10 cv) of nominal power, and output tension of 120/240 V monophase. Soybean biodiesel used in the experiment was made by means of transesterification at the Biofuel Laboratory of UNIOESTE, following the specifications of the norm ASTM D6751 and their measurements to the same norm. The catalyst used was 1% potassium hydroxide (KOH) in relation to the initial volume of oil; the alcohol used was methanol, with the addition of 25% of the initial volume of oil.

In order to assess the mass of fuel consumed, an external storage tank was used, as well as a precision scale by GEHAKA model BG-2000, with a precision of 0.02 g.

Execution period of each test was counted in a digital stopwatch, which made it possible to obtain data for fuel consumption. Equation 1 shows the calculation of fuel consumption performed in each of the performance tests.

$$Cons = \frac{Mi - Mf}{\Delta t} \quad (1)$$

In which, *Cons* is the fuel consumption ($g.s^{-1}$); *Mi* is the initial fuel mass (g); *Mf* is the final fuel mass, (g) and Δt is the experiment period (s).

In what concerns the loads used during the test, the simulation was performed by using a bank of electrical resistances. The cycle of loads adopted started from lower loads; the following cycles were applied: 1.0; 2.0; 3.0; 4.0 and 5.0 kW, as well as 4 (four) replications for each experiment. The assessment of the specific fuel consumption was determined according to the load variation of the engine-generator set, running on soybean biodiesel and diesel. The following equation presents the calculation of specific fuel consumption for a determined load:

$$SFC = \frac{3600 * Cons}{V * I} \quad (2)$$

In which, SFC is the specific fuel consumption ($g.kW^{-1}.h^{-1}$); *Cons* is the fuel consumption ($g.s^{-1}$); *V* is the output tension (V); *I* is the electric current (A)

In order to determine the calorific power of fuels, a calorimeter was used (model E2K). For this experiment, fuel portions of about 0.5 g were separated. The method for determining superior calorific power with the calorimeter consisted of pressurizing with a pump, the adiabatic container that kept the sample; such container was coupled to the ignition cord. Pressure kept in calorimeter E2K was 30 atm (3.00 MPa). Experiments with incomplete combustion were ignored. In that sense, it was possible to assess the lower heating value of fuels.

Higher heating value (Equation 3) of the compositions was determined by the equation described in Volpato et al. (2009), which takes into account the lower heating value:

$$LHV = HHV - 3.052 \quad (3)$$

In which, LHV is the lower heating value ($MJ.kg^{-1}$) and HHV is the higher heating value ($MJ.kg^{-1}$)

Another parameter used in the assessment of the engine-generator set was its efficiency in converting the fuel's chemical energy into electricity. Efficiency calculation of the engine-generator set was performed as shown in Equation 4.

$$\eta = \left(\frac{3600}{LHV \times SFC}\right) x100 \quad (4)$$

In which, η is the set efficiency (%); SFC is the specific fuel consumption ($kg.kW^{-1}h^{-1}$); LHV is the lower heating value ($MJ\ kg^{-1}$)

In order to quantify the emission of gases, an emission and combustion quality analyzer was used: model PCA3-285KIT/24-8453, by Bacharach. The analyzer has calibration certificate N° 1011/AN5420, dated from 24/11/2010 for temperature and concentration items. For the emissions test, the equipment's capture probe was exposed in the combustion gases exhaust area, and then it was necessary to wait for the stabilization of values. Such process was repeated four consecutive times. Quantified gases were the emissions of NO and NOx.

Statistical tests for specific fuel consumption and efficiency consisted of variance analysis (ANOVA) and for the comparisons of averages, Tukey's test was applied at 5% of probability, which was performed on software SISVAR.

Table 1. Averages of analyzed properties for soybean biodiesel and diesel.

Property	Soybean biodiesel	Diesel
Higher heating value ($MJ.kg^{-1}$)	38.722	43.616
Kinematic viscosity, 40°C ($mm^2.s^{-1}$)	4.68	3.01
Specific density ($g.cm^{-3}$)	0.885	0.845
Flash point (°C)	130	52.5

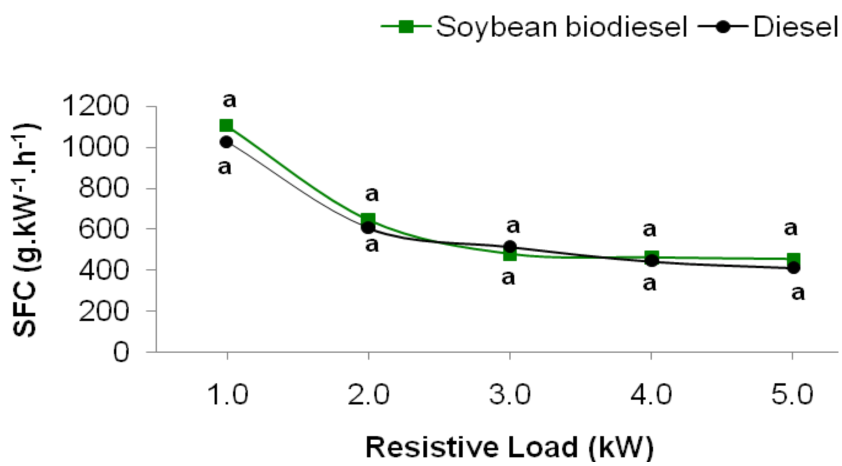

Figure 1. Specific fuel consumption according to the applied load. Treatments averages followed by different letters significantly differ from each other by Tukey's test at 5% of significance.

RESULTS AND DISCUSSION

Table 1 shows the properties obtained in the laboratory for the soybean biodiesel and mineral diesel used for the tests with the engine-generator set. The average for higher heating value presented was 11.22% lower that soybean biodiesel. Kinematic value was much higher for soybean biodiesel as well (4.68 $mm^2.s^{-1}$). These two properties are extremely important in understanding the engine-generator set's behavior when running on these fuels.

Figure 1 shows the behavior of SFC according to the load variation applied to the generator. Even though there were no statistical differences, soybean biodiesel presented higher average SFC, which was 4.3% superior to diesel. Except for load 3 kW, for all other loads, soybean biodiesel presented specific consumption superior to that of mineral diesel.

The results follow the same trend as those presented by Hilbert et al. (2002) in which they obtained an average increase of 9.5% in the SFC with the use of biodiesel when compared with diesel oil, the same was found by Maziero et al. (2006), in an analysis of a 92 kW engine, when an increase of 10% was verified in the SFC when using pure biodiesel (B100) in comparison with diesel.

According to Torres et al. (2006), when performing tests with a 7.36 kW power engine, running on diesel oil and pure biodiesel (B100), the specific fuel consumption was 20% higher with biodiesel when compared with diesel.

Volpato et al. (2009), by using soybean biodiesel and mineral diesel oil in a four-stroke cycle diesel engine with nominal power of 75 cv (56 kW), obtained a reduction of up to 14.66% in the SFC of the engine running on biodiesel; however, the same authors, when using olive biodiesel, obtained an increase of 12.68% in comparison with diesel.

Graboski and McCormick (1998), by using four-stroke engines, demonstrated that there is usually an increase in the SFC and NOx in biodiesels in relation to diesel oil. The viscosity difference between biodiesel and diesel may also be an important factor in the difference of specific consumption; Xué et al. (2011) reported that there is an increase in consumption as density and viscosity are raised. In this study, there were significant differences between fuels for these characteristics (Table 1), which influences the SFC. Efficiency in the conversion of the fuel's chemical energy into electric energy in the engine-generator set was measured as shown in Figure 2.

For all loads, soybean biodiesel presented higher

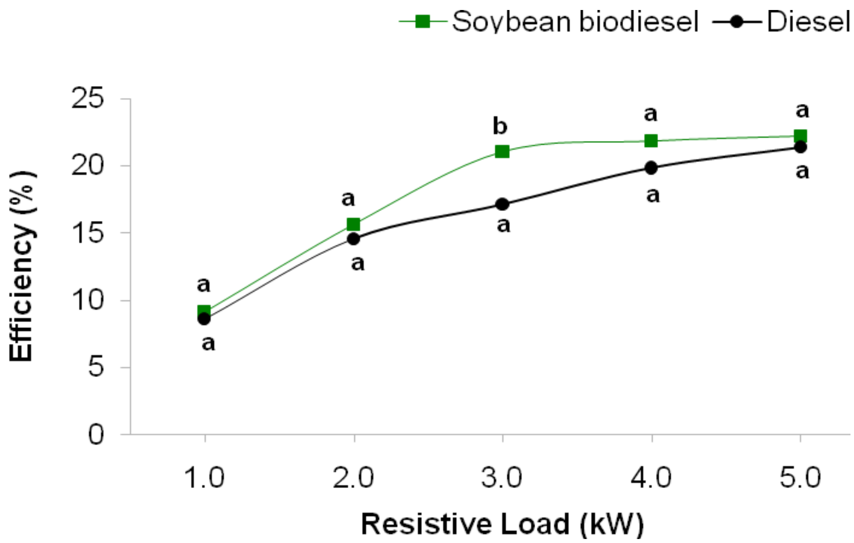

Figure 2. Efficiency of the engine-generator set in converting the fuel's chemical energy into electric energy. Treatments averages followed by different letters significantly differ from each other by Tukey's test at 5% significance.

efficiency in the conversion of the fuel's chemical energy into electric energy in the engine-generator set, given that for the 3 kW load, both fuels were considered statistically different, with 21.03% of efficiency for soybean biodiesel and 17.15% for diesel. If one takes into account the differences among all loads, soybean biodiesel's efficiency was 9.05% higher than diesel's. As the SFC for both fuels was close, there was higher efficiency for biodiesel, due to the fact that it presents lower inferior calorific power, what implies a higher relation in conversion (Equation 4).

Silva et al. (2012) observed an increase of 3% for all studied loads by using chicken fat biodiesel; such result was inferior to that found in the present study. Barbosa et al. (2008), by using a 58.2 kW (78 cv) cycle diesel engine, obtained an average efficiency gain of 4% when using 100% soybean biodiesel in comparison to mineral diesel.

Yehliu et al. (2010), when testing an engine running on soybean biodiesel (B100) and diesel oil, obtained an efficiency decrease of 6 to 8% with soybean biodiesel in comparison with mineral diesel, what may be explained by the fact that the engine was not optimized for such fuel, so the advanced combustion process caused a negative balance between the indicated engine working and mechanical losses, which resulted in efficiency decrease.

Kegl (2006), when performing tests with canola biodiesel as compared to diesel oil, verified that the efficiency had a slight increase with canola biodiesel, as there was a specific fuel consumption increase in comparison to diesel oil.

Apart from being a renewable source, another feature of biodiesel is the trend of emitting fewer gases than other conventional fuels, such as diesel. In the present study, in what concerns the emissions of NO, soybean biodiesel presented a reduction when compared with diesel for all analyzed loads, as shown in Figure 3.

The decrease of NO emissions with soybean biodiesel in relation to diesel was averagely 84% for all loads. According to Rakopoulos and Giakoumis (2009), NO depends on combustion temperature, oxygen level in the combustion chamber and on combustion period. One of the explanations for the decrease of NO in this study is that according to Ghobadian et al. (2009), biodiesel contains oxygen in its structure, thus, the oxygen kept in the biofuel is the main reason for a more complete combustion, causing a reduction in the emission of gases.

The result presented in relation to the emissions of nitric oxide (NO) is similar to that observed by Pereira et al. (2007), who reported a decrease of 446 ppm of NO with diesel oil to 407 ppm of NO with soybean biodiesel, totalizing a 9% reduction. Chaves et al. (2012) found a reduction of approximately 12% in the emissions of NO by using residual frying oil.

Regarding nitrogen oxides (NOx), for all resistive loads, soybean biodiesel presented a reduction as compared to diesel (Figure 4).

Soybean biodiesel's average NOx reduction in comparison to diesel was 54%; such decrease was also observed by Pereira et al. (2007), who obtained a reduction of 9% when using soybean biodiesel in comparison to diesel, just like Kegl (2008), who observed a reduction of NOx emissions with canola B100 as compared to diesel.

Hess et al. (2007), observed a reduction of 5.6% in the soybean biodiesel emissions of NOx in relation to diesel. Murillo et al. (2007) reported a NOx reduction of 16%,

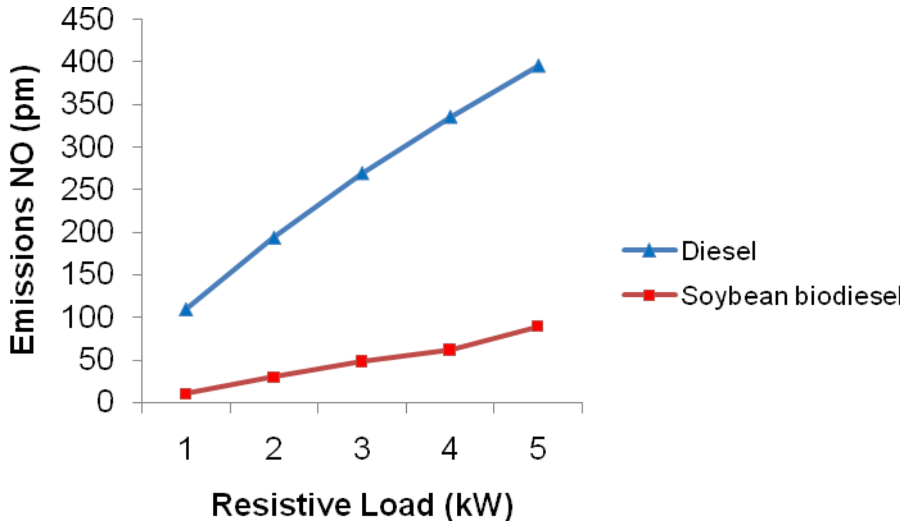

Figure 3. Means of NO emissions for both fuels in different resistive loads.

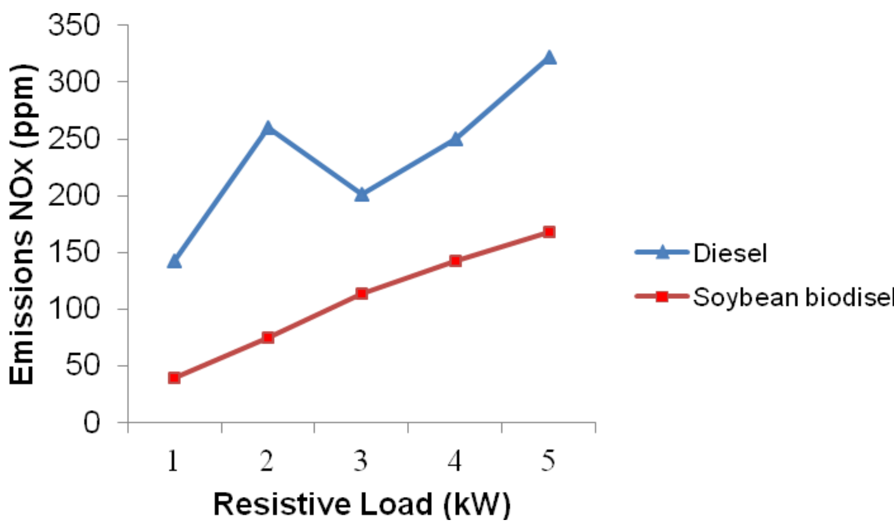

Figure 4. Averages of NOx emissions of both fuels for different resistive loads.

Table 2. Exhaust gases temperature with the application of different resistive loads in the engine-generator set.

Load	Diesel	Soybean biodiesel
1	182.2	137.5
2	193.1	154.2
3	222.2	157.3
4	257.8	177.5
5	217.0	162.6

and affirmed, as Ghorbani et al. (2011) did, that NOx emissions are highly dependent on temperature, due to the high activation energy necessary for the involved reactions, given that the higher the temperature is, the higher the gases emission (Table 2).

As literature mentions works in which gases emissions are directly related to the gases exhaust temperature, dispersion analysis were made between exhaust temperature and emissions of NO and NOx (Figure 5).

Figure 5 shows that regarding soybean biodiesel, there is a high correlation, which is 80% for both gases, which explains that the increase of gases emissions occurs as gases exhaust temperature increases. It is noticed that obtaining a better efficiency in energy conversion and higher CEC, results in lower temperatures at the exhaust, and the efficiency will be higher due to the fact there is a

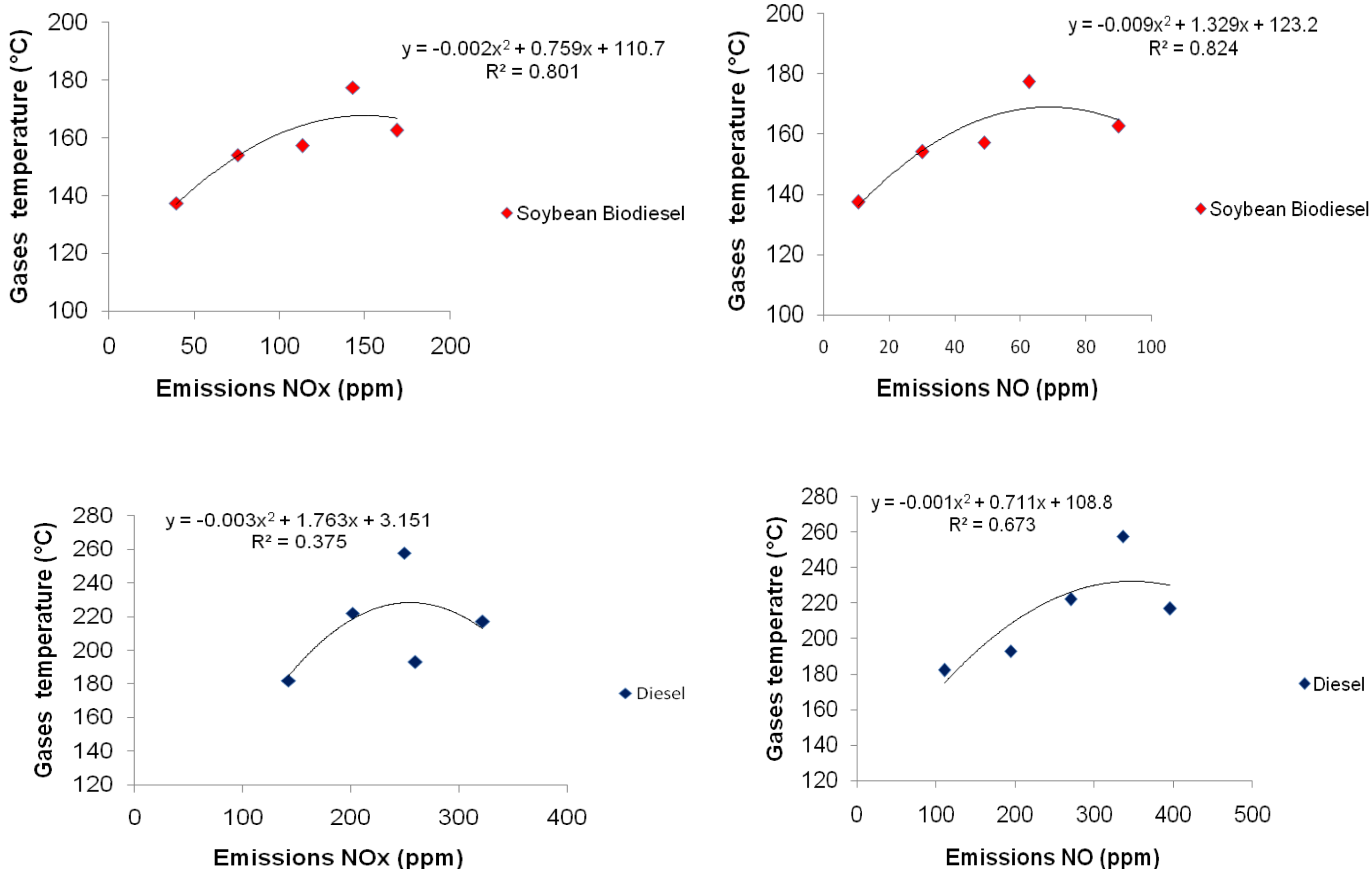

Figure 5. Correlation between gases exhaust temperature and NO and NOx emissions.

minor loss of thermal energy in the exhaust gases, so the temperature is lower.

With regards to diesel, such correlation was lower, which demonstrates that there is a shorter relation between these two variables, which was 37% (low correlation) for NOx and 67% (average correlation) for NO.

According to Szybist et al. (2005) and Leung et al. (2006), NOx emissions increased most of the times, as proved by Buyukkaya (2010), who obtained an increase of 12% in NOx emissions with canola biodiesel in relation to diesel. The increase becomes a large obstacle to the generalized use of biodiesel, which may be avoided by modifying the properties of biodiesel or adjusting the engine used. Valente et al. (2010) claim that NOx emissions are strongly affected by the engine's working conditions.

For the present study, gases emissions were fewer when compared to diesel, which allows one to use soybean biodiesel in energy generation, with a reduction of NO and NOx emissions.

Conclusion

Soybean biodiesel presented a consumption increase of 4.3% in the average of all resistive loads, which shows great potential for being used in energy generation without causing significant increases in the SFC.

Soybean biodiesel efficiency has proved to be superior to that of diesel of all resistive loads. Regarding the emissions, soybean diesel provided a reduction of 84 (NO) and 54% (NOx) when compared with diesel oil.

REFERENCES

ANP - Agência Nacional do Petróleo, Gás Natural e Biocombustíveis.NacionalProductionofPure Biodiesel - B100 (barrelsofpetroleumequivalent). Brasília: Governo Federal. 2012. RetrievedSeptember 18, 2012, from<http://www.anp.gov.br/?pg=61929&m=&t1=&t2=&t3=&t4=&ar=&ps=&cachebust=1348336489789

Barbosa RL, Silva FM, Salvador N, Volpato CES (2008). Comparative performance of a cycle diesel engine using diesel and biodiesel mixtures. Ciênc AGROTEC. [online] 32(5):1588–1593.

Buyukkaya E (2010). Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics. Fuel. 89(10): 3099-3105.

Chaves LI, Souza SNM, Rosa HA, Baricatti RA, Nogueira CEC, Secco D, Wazilewski WT, Avaci AB, Breneissen PJ, Silva MJ, Veloso G (2012). Fuel specific consumption and emission analysis in a cycle diesel motor generator using diesel and biodiesel from waste frying oil blends. Afr. J. Biotechnol. 11(80):14578–14585.

Costa Neto PR, Ramos LP, Rossi LFS, Zagonel GF (2000). Producing biofuel alternative to diesel fuel by transesterification of soybean oil used in frying. New Chem. 23:4.

Flores IS, Godinho MS, Oliveira AE, Alcântara GB, Monteiro MR, Menezes SMC, Lião LM (2012).Discriminationof biodiesel blends with^{1}H NMR spectroscopyand principal component analyses. Fuel. 99:40–44.

Gerper JV (2005). Biodiesel processing and production. Fuel Process Tech, 86:1097- 1107.

Ghobadian B, Rahimi H, Nikbakht AM, Najafi G, Yusaf TF (2009). Diesel engine performance and exhaust emission analysis using waste cooking biodiesel fuel with an artificial neural network. Renew. Energy. 34:976–982.

Ghorbani A, Bazooyar B, Shariati A, Jokar SM, Ajami H, Naderi A (2011). A comparative study of combustion performance and emission of biodiesel blends and diesel in an experimental boiler. App. Energy. 88(12):4725–4732.

Graboski MS, McCormick RL (1998). Combustion of fat and vegetable oil derived fuels in diesel engines. Prog. Energ. Comb. Sci. 24(2):125–164.

Hess MA, Haas MJ, Foglia TA (2007). Attempts to Reduce NOx Exhaust Emissions by Using Reformulated Biodiesel. Fuel Proc. Technol. 88:693–699.

Hilbert JA, Tesouro MO, Aucuná MO, Pincu MS (2002). Comparative performance of biodiesel and diesel fuel in agricultural tractors. Buenos Aires: INTA.

Kegl B (2006). Experimental investigation of optimal timing of the Diesel engine injection pump using biodiesel fuel. Energ. Fuels. 20(4):1460–1470.

Kohlhepp G (2010).Situation analysis of the production of ethanol and biodiesel in Brazil. Adv. Stud. 24(68):223-253.

Leung DYC, Luo Y, Chan TL (2006). Optimization of Exhaust Emissions of a Diesel Engine Fuelled with Biodiesel. Energ.Fuels. 20(3):1015–1023.

Maziero JVG, Côrrea IM, Trielli MA, Bernardi JÁ, D'agostini MF (2006). Assessment of pollutant emissions of a diesel engine using biodiesel fuel as sunflower. Magazine Engineering in Agriculture, Viçosa-MG.14(4):287-292.

Murillo S, Miguez, JL, Porteiro J, Granada E, Moran JC (2007). Performance and exhaust emissions in the use of biodiesel in outboard diesel engines. Fuel 86(12-13):1765-1771

Pereira RG, Oliveira CD, Oliveira JL, Oliveira PCP, fellowsc CE, Piamba OE (2007). Exhaust emissions and electric energy generation in a stationary engine using blends of diesel and soybean biodiesel. Renew. Energ. 32(14):2453-2460.

Rakopoulos CD, Giakoumis EG (2009). Diesel engine transient operation: principles of operation and simulation analysis. J. Automobile Eng. p.1

Silva MJ, Souza SNM, Souza AA, Martins GI, Secco D (2012). Motor cycle diesel generator under five ratios of biodiesel with diesel fuel. Rev. Bras. Eng. Agrí. Amb. 16:320-326.

Szybist JP, Boehman AL, Taylor JD, McCormick RL (2005). Evaluation of formulation strategies to eliminate the biodiesel NOxeffect. Fuel Proc. Technol. 86(10):1109–1126.

Torres EA, Santos DC, Souza DVD, Peixoto LB, França T (2006). Test cycle diesel stationary engines using diesel and biodiesel. AGRENER.

Valente OS, Silva MJ, Pasa VMD, Belchior CRP, Sodré JR (2010). Fuel consumption and emissions from a diesel power generator fuelled with castor oil and soybean biodiesel. Fuel. 89(12):3637–3642.

Volpato CES, Conde AP, Barbosa JÁ (2009). Performance four-stroke diesel engine fed with soybean oil biodiesel (B 100). Ciênc AGROTEC. [online] 33(4):1125-1130.

Volpato CES, Conde AP, Barbosa JÁ, Salvador, N (2009). Performance of cycle diesel engine using biodiesel of olive oil (B100). Ciênc AGROTEC. [online] 36(3):348-353.

Xué J, Grift TE, Hansen AC (2011). Effect of biodiesel on engine performances and emissions. Renew. Sustain. Energy Rev. 15:1098-1116.

Yehliu K, Boehman AL, Armas O (2010). Emissions from different alternative diesel fuels operating with single and split fuel injection. Fuel. 89(2):423–437.